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PLATE IX

Globular Star-Chester Messier 13 *Herculis.*

Photographed by G. W. Ritchey with the 60-inch Mt. Wilson Reflector, June 6, 7, 8, 1910. Total exposure 11 hours. Area of sky shown, about 26 x 21 minutes of arc.

Journal of the Royal Astronomical Society of Canada, 1928.

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VOL. XXII, No. 8 OCTOBER, 1928 Whole No. 177

THE MODERN PHOTOGRAPHIC TELESCOPE AND THE NEW ASTRONOMICAL PHOTOGRAPHY

By G. W. RITCHEY

PART III

THE RITCHEY-CHRÉTIEN APLANATIC REFLECTOR

In the preceding article I described a rigorous comparison, in the laboratory, of the out-of-axis star-images and fields of a Newtonian and a Ritchey-Chrétien reflector, each of 19.9 inches aperture and 136 inches focal length. The images given by the latter type of telescope are so extremely small and symmetrical that in order to utilize them to the utmost limit for astronomical photography we must introduce all possible refinements in the telescope mounting dome and building; it is a fortunate coincidence that the extraordinary compactness of these parts renders such refinements both practicable and economical.

In the 19.9-inch Ritchey-Chrétien reflector just mentioned, the distance between the vertices of the large concave and the small convex mirrors is only 41.73 inches; this distance is about 2.1 times the aperture of the large mirror. In a second Ritchey-Chrétien reflector which I have designed, the aperture of the large mirror is 40 inches; its focal ratio is 4 to 1; the magnification given by the principal convex mirror is 1.7 times; the equivalent focal length of the telescope is therefore 160 inches $\times 1.7 = 272$ inches, or 22.67 feet; and the distance between the vertices of the two mirrors is

96 inches, or 2.4 times the aperture of the large mirror. In each telescope here mentioned the length of the telescope tube is less than one-half that of the corresponding Newtonian reflector of the same aperture and focal length.

The 40-inch aplanatic reflector is being designed in minute detail for France, at the request of the Duke de Gramont, president of the council of the *Institut d'Optique*. The over-all length of the tube required when the 22.67-feet focal length of this telescope is used, is 10.5 feet. When a second convex mirror is substituted, which gives an *approximate* aplanatic field, a focal length of 40 feet is obtained for spectroscopic work and for photographic work requiring a larger scale. The over-all length of tube required for the 40-feet focal length is 11.8 feet; this requires an interior diameter of dome of 21 feet. A schematic drawing of the mounting, dome and building for this 40-inch telescope is shown in Figure 1.

Some of the refinements made practicable by the compact form of the Ritchey-Chrétien reflector are as follows:

Protection from the effects of temperature changes. For the first time in the history of telescope design it is now practicable to enclose the entire telescope, of whatever aperture, in a constant-temperature chamber inside of the dome, throughout the day, in order to hold all parts of the telescope, optical and other, at the expected night temperature. If the dome and building be protected by an effective exterior sun-shield of thin metal or other material, as was done by the writer in the case of the 60-inch Mt. Wilson reflector, a very small refrigerating apparatus will be sufficient to hold the mirrors and mounting, within the chamber, at a constant temperature throughout the day. My experience in using such a chamber for protecting the large mirror, the massive parts of the mounting, and the lower half of the tube of the 60-inch reflector showed the great importance of such a protection, even when the light upper end of the tube was not protected, and when no refrigeration was used. The slow changes of figure (form) of the large mirror in the first half of the night were much reduced, as were also the slow changes of focal plane. The constant-temperature

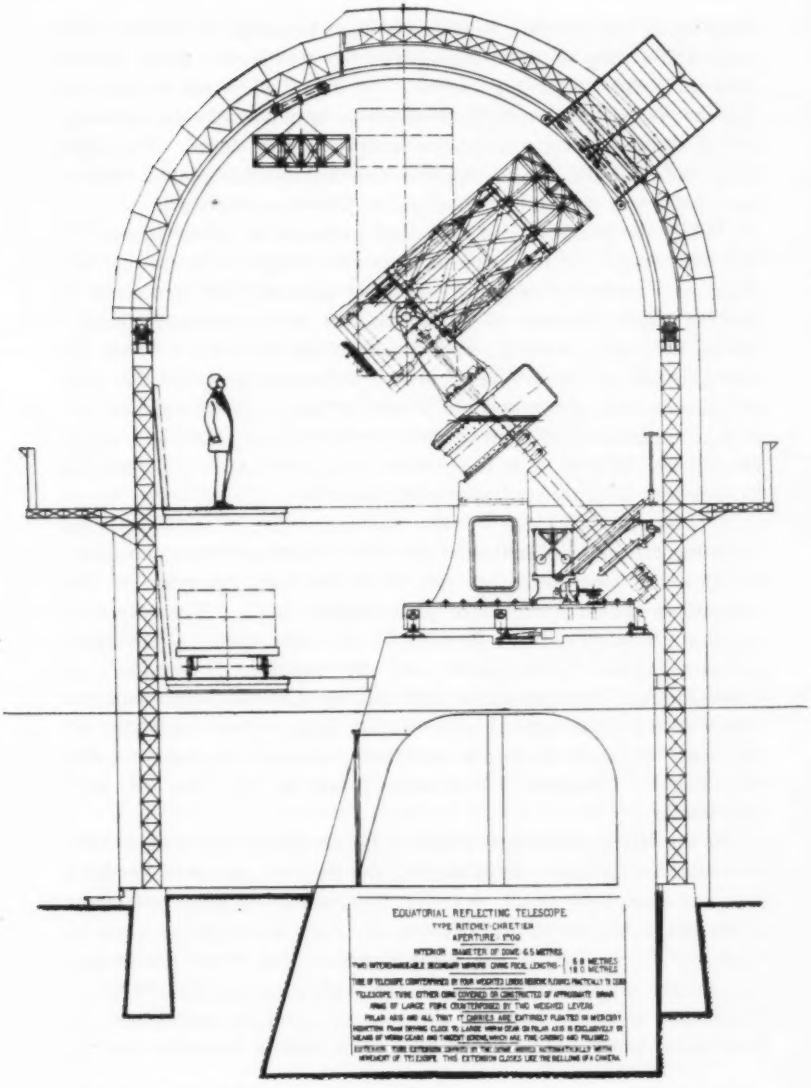

Fig. 1. Equatorial Reflecting Telescope, Ritchey-Chrétien Type. Aperture 40 inches; interior diameter of dome 21.1 feet.

chamber of the compact Ritchey-Chrétien telescope is circular, with walls and ceiling of light, high-grade felt two inches thick, quilted between covers of strong canvas. At night, when not in use, the chamber is raised by suitable mechanism, is closed like an umbrella, and is drawn closely against the interior of the dome. The light, soft, folding walls of the chamber are thus quickly placed entirely out of the way of the telescope and of all other mechanism.

While the chamber just described protects the telescope mirrors and mounting from the large temperature changes between day and night, still further attention to the steel skeleton tube is needed, to prevent slight changes of its length due to temperature changes during the night,—that is, while the telescope is in use. There are two solutions of this problem: first, it is practicable to protect each of the members of the short tube with a thick layer of cork or felt, so that expansion and contraction are rendered very slow and small; second, the skeleton tube is so short and light that it is practicable to construct it entirely of approximate *invar*.

Decrease of flexures of the telescope tube. In Newtonian reflecting telescopes flexures of the tube result in errors, constantly changing in magnitude, in the *centering and squaring* of the mechanism which carries the photographic plate. The effect of constantly-changing, large flexures of the tube upon the sharpness of astronomical photographs can be readily understood. In Cassegrainian, Schwarzschild and Ritchey-Chrétien reflectors the coincidence of the optical axis of the large mirror with that of the small mirror is absolutely necessary to secure the best possible star-images. Flexures of the tube result in the loss of such coincidence.

In the Ritchey-Chrétien reflector the length of the tube is only about twice as great as its diameter; the flexures of a well-designed tube are therefore small, even in the case of a great telescope. From this cause alone, the flexures are only one-eigth as great as those of a tube having the same diameter and twice the length. But we are endeavoring to reach the highest attainable degree of refinement in every detail of the telescope and its accessories, by economical means. The shortness of the tube is favorable for the

use of four or eight counterpoise levers which, at all possible inclinations of the tube, decrease its flexures to much less than one per cent of those of the same tube when not counterpoised. The extreme accuracy of alignment or adjustment of mirrors is thus preserved. A practical method of using these counterpoise levers without increasing the exterior dimensions of the skeleton tube has been thoroughly worked out.[1]

Other results of the shortness of the telescope tube. The size, weight and cost of the tube and of nearly all of the mechanical parts of the telescope are substantially decreased.

The diameter of the dome required is one-half of that needed for the best type of reflectors in use at present; the weight and cost of the dome are therefore reduced to one-eighth. The diameter of the steel building which protects the telescope and supports the dome is reduced to one-half of that formerly required; but for a given aperture of telescope the *height* of the building should not be decreased; the weight and cost of the building are reduced to approximately one-third. (Fig. 7, July-August issue, p. 217).

Because of the small size of the dome and building it is practicable to construct them with every known means for securing the best attainable *local* conditions, atmospheric and other, for astronomical observation.

Plans have been studied for years, and designs have been completed, for the safe and quick interchange at night, first, of the various tube-extensions which carry the small secondary mirrors, and second, of at least two large primary concave mirrors as well. The usefulness of such interchange has been explained in my articles in the two preceding numbers of the JOURNAL. The interchange of tube-extensions is greatly facilitated in this compact type of telescope, because of the shortness of the tube and the small dimensions of the dome.

An *exterior* extension of the telescope tube, outside of the dome, is carried entirely by the dome, not by the telescope. This protects

[1]In all the writer's later designs, the pivot-bearings for all counterpoise levers, wherever they occur in the telescope mounting and in the mechanical flotation-system of the mirrors, are of the Timken-roller type.

the photographic plate and the interior of the dome from skylight, and protects the telescope from wind and from radiation to the night sky. This extension is moved, automatically, very nearly with the equatorial motion of the telescope. Its motion in azimuth is given by the automatic, electrically-controlled rotation of the dome; its motion in altitude is given by the automatic, electrically-controlled movement of its rolling carriage up and down the slit of the dome. It is collapsible in the direction of its length, like the bellows of a camera, and is entirely beneath the dome-shutter when the latter is closed.[2]

An equatorially-mounted observer's carriage. With this type of telescope the observer works always near the floor of the dome and near the center of motion of the telescope. In order to increase still further the convenience and efficiency of the observer, I have invented an equatorially-mounted observer's carriage, with its polar axis in the prolongation (to the north) of the line of the polar axis of the telescope, (Figure 2). This carries the observer *smoothly, synchronously, precisely* with the motion of the telescope; a condition of much importance for the utmost facility, refinement and speed in guiding in direct photography, and for all observing-work requiring great concentration and skill. When the telescope is pointed near the pole this observer's carriage is rolled out of the way on circular tracks.

For economy of construction, for reaching the pole of the heavens, and for facility of adjustment of the entire telescope as a unit, in altitude and azimuth, the form of telescope-mounting with short, open fork, like that of the 60-inch Mt. Wilson reflector, is preferred even for great sizes of the Ritchey-Chrétien telescope, (Figs. 1, 2). For large sizes the fork is constructed in three parts: an extremely rigid crosshead or base of the fork, and two arms. The arms of the fork are made long enough to permit entire convenience in observing clear to the pole. The flexures of the two arms are decreased practically to zero by means of a very strong

[2]It should be noted that the method of automatic electric control is applicable to the type of *observing-platform* employed with the 60-inch and 101-inch Mt. Wilson reflectors when they are used as Newtonians.

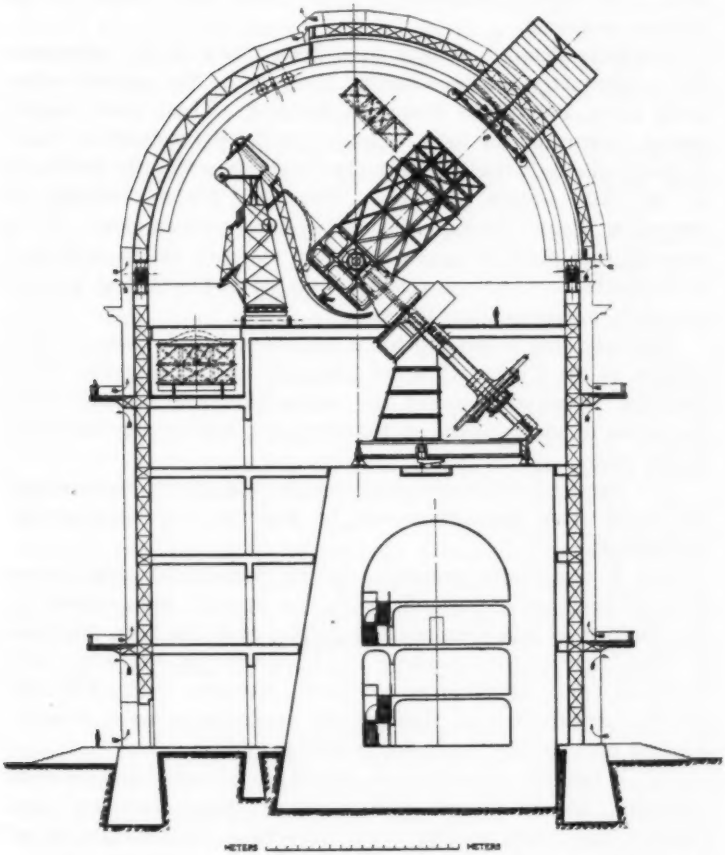

Fig. 2. Diagram of the Mounting, Dome and Building of a Six-metre (19.7-foot) Equatorial Reflecting Telescope of the Ritchey-Chrétien Type.
An equatorially mounted observer's carriage and an automatic, exterior tube-extension are shown. The dome is about 25 per cent. larger than the largest observatory domes now in use.

counterpoise lever (with universal joint) in the interior of each arm. The tubular supports of these levers are carried by the massive crosshead.

Complete detailed designs have been made in my laboratory for a four-meter Ritchey-Chrétien telescope of the compact equatorial form, and for its dome and building. These plans include optical mirrors of the light, cellular, ventilated construction, made of plates one inch thick, of *low expansion glass* recently developed by the Saint Gobain Company. This glass has a coefficient of expansion about one-half that of ordinary crown-glass. It is expected that plates of pyrex, and even of fused quartz, will soon be available for built-up, cellular disks of sufficient size for the secondary mirrors of this telescope.

The following points should be mentioned here because of their relation to the Ritchey-Chrétien telescope, and because they illustrate the interdependence of the various methods for improving the details of astronomical photography, which are being developed by the writer.

(a) Special photographic emulsions having greater sensitiveness and much finer granulation will be available for astronomical photography.

(b) A remarkable invention, having innumerable applications in many branches of scientific work, has recently been applied by M. Chrétien to astronomical photography, and has been described by him before the Academy of Sciences of Paris.[3] This invention, *the multiple-lens pellicule,* increases many-fold the *effective* sensitiveness of photographic emulsions as used in astronomical photography, including spectrography.

(c) When the improvements named in (a) and (b) are used separately, and to a much greater degree when they are used together, they make possible, on the one hand, the photography of fainter stars, nebulae and spectra than have been photographed in the past, and on the other hand, the use of greater ratios of focal length to aperture in photographic telescopes and in the cameras of spectrographs, than those now considered most efficient.

[3]H. Chrétien, *Comptes rendus des séances de l'Académie des Sciences,* Vol. 186, page 139, January 1928.

(d) These greater ratios have two favorable effects: first, they give greater scale of the photographs without the necessity of larger telescope apertures; second, they result in out-of-axis images having still smaller angular diameter (so far as aberration-effect is concerned) in the new types of reflector and in the old types.

(e) Both of the effects just named are important because they permit increased accuracy of measurement of astronomical photographs.

(f) With the Ritchey-Chrétien telescope the larger ratios of focal length to aperture are secured with very slight increase of length of tube and of diameter of dome.

Probably many readers have wished to ask whether the new types of mirror-surfaces are more difficult for the optician to produce than are the paraboloid and hyperboloid of Newtonian and Cassegrainian reflectors. The former surfaces are more difficult, because they depart farther from the nearest *spherical* surfaces than do the latter. This statement applies to the mirror-surfaces of the Schwarzschild aplanatic type of reflector as well as to those of the Ritchey-Chrétien. This fact might be regarded as a serious objection to the new types. Instead, it is purely a matter of intelligent experimenting, to find the proper methods of work and the proper design of optical machine, to produce the new surfaces without seriously greater difficulty than the old. Much valuable experience in this work has already been gained in my laboratory.

Of much interest is a rigorous comparison of Newtonian and Ritchey-Chrétien telescopes of equal aperture and focal length, with respect to the degree of accuracy of measurement which is possible with photographs taken with each. Of almost equal interest is a similar comparison with respect to the magnitude of the faintest stars which can be photographed with each telescope. In both cases the comparison applies to fields of any diameter between 4′ and 40′. In both cases the difference in results is due in large part to the relative concentration and symmetry of form of the out-of-axis images given by the two telescopes. But if the comparison be made with telescopes of medium and large sizes, the

difference in results is due in large part, also, to the relative refinements which are possible in the mechanical parts of the two types.

While I reserve for a future paper a rigorous comparison of celestial photographs taken with the two types of reflectors, Newtonian and Ritchey-Chrétien, I shall describe here the results which we may expect to secure in photographing a difficult object,—a dense globular star-cluster, with a large reflector of the latter type. To aid in this discussion I shall describe first a photograph of Messier 13 *Herculis,* taken with a large Newtonian reflector.

Plate IX is from a negative of this cluster, which negative represents the highest limit which I am able to attain with the refinements of methods which I had developed up to 1910. The total net exposure of this photograph, eleven hours, was made on three successive nights, June 6, 7 and 8, 1910, at the Newtonian focus of the 60-inch Mt. Wilson reflector. The exposure was made by the writer alone, M. Chrétien being present.

The polar axis of the 60-inch reflector, and all that it carries, are floated in mercury to reduce friction. The reduction of speed from the driving-clock to the polar axis, 86,400 to 1, is made in two steps only, by two worms, (tangent screws), and two worm-gears, which had been cut, ground and polished, under my direction, with nearly the same degree of refinement as that given to grinding and polishing the optical mirrors. The same degree of care had been given also to the end-thrust bearings. These refinements gave extreme accuracy and smoothness of rotation to this great telescope during the years 1909 and 1910. In designing and constructing this telescope I had made ample provision by which the accuracy and smoothness of these parts could easly have been preserved for a century without deterioration.[4] The telescope tube is extremely rigid; the optical parts and the photographic mechanism were therefore kept in good alignment even when the telescope was used far from the zenith; long exposures were thus permitted, without serious effects of flexures.

The dome and building had been designed and constructed with

[4]For a much fuller description see *Astrophysical Journal,* Vol. 29, April 1909.

much care to avoid injurious local temperature effects. The telescope itself was protected throughout the day in an insulating chamber or canopy.

Some of the refinements used in making the Newtonian photograph: The telescope mirrors had just been resilvered. The aperture of the large mirror was reduced to 50 inches, (the ratio of focal length to aperture being thus increased to 6 to 1), in order to decrease both the slight temperature-effect near the edge of the large mirror, and also the size of the out-of-axis star-images. Guiding was done with the improved double-slide plate-carrier; on an average, two corrections per second were made, of the position of the guide-star with reference to the fine cross-lines in the principal guiding eye-piece. Refocusing, accurate to 0.001 inch, was done every thirty minutes throughout the three-night exposure, by means of the *knife-edge* focusing device. Correction for slight rotation of field was made at the time of each refocusing; this was done by means of a second guide-star and the second guiding eye-piece. During all instants of inferior atmospheric definition the photographic plate was covered.[5]

The photographic plate used was the commercial one *Seed 23*. While not of the greatest sensitiveness, this plate has much finer granulation, and has, in general, a thinner film of sensitive emulsion than the most sensitive commercial plates; both of these features assist in photographic definition or resolution, and both features, especially the latter, assist in reducing *diffusion* of the photographic images in the sensitive film. The single objection to the use of these finer-grained plates, as compared with the use of the most sensitive commercial plates obtainable, is that they require about two and one-half times longer exposure to secure the same intensity of photographic images.[5]

The Mt. Wilson photograph was made at an altitude of 5,700 feet above sea-level, in a mild, semi-tropical climate; a location where conditions of atmospheric definition and transparency are certainly much better, in general, than those at observatories in northern Europe and in the northern part of the United States.

[5]Ritchey *The Astrophysical Journal*, Vol. 32, 1910, Page 283.

I have described some of the conditions which contributed to the making of the photograph of Messier 13 *Herculis,* in part that we may have a basis of comparison with conditions which will be described later in this article.

Returning now to the Mt. Wilson photograph, we should note that the clear field of the original negative is 38′ (about 3¼ inches) square. On a large glass positive made from this negative, Miss Ware counted 26,700 stars outside of the circle where superposition of the star-images begins.[6] Later, on a still larger glass positive of which the central regions had been exposed for a much longer time than the outer regions, the writer counted 40,520 stars outside of the dense central area 2′.5 in diameter. In the original negative the smallest photographic star-images distinctly seen in the dark openings not far from the center of the photograph measure 1″.03 in diameter.[6]

An estimate of the photographic magnitude of these faintest stars indicates that this is approximately 21.3 of the Harvard scale.[7] This estimate is based on a comparison of the faintest star-images with those on a negative of Messier 3 which the writer secured on the night of April 9, 1910. Professor E. C. Pickering estimated the faintest stars shown on the negative of Messier 3 to be at least as faint as twentieth magnitude. Shapley says: "The original negative (of Messier 3) shows more than twenty thousand stars outside of the central burned-out area, the smallest images being fainter than twentieth magnitude."[8] The negative of

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[6] *Monthly Notices,* R.A.S., Vol. LXX, 1910, page 647. While studying this photograph M. Chrétien discovered, in 1910, the ellipticity of form of this cluster.

[7] The computed magnitudes of the faintest stars visible in the great refractors at Lick and Yerkes Observatories are 16.8 and 17.0 respectively. (See E. C. Pickering, *Astr. Nach.,* 1905, No. 4026). Professor Pickering concludes that, allowing for the loss of light due to the absorption in large lenses, the magnitude of stars "barely visible" with the Yerkes refractor may be assumed to be not far from 16.5. Hence this photograph of Messier 13 reveals stars which are nearly one hundred times fainter than those at the visual limit of the largest and most perfect refractors.

[8] H. Shapley, *Publications A.S.P.* Vol. 29, 1917, page 247.

Messier 3 was exposed for three hours; the smallest star-images shown on it are 1".15 in diameter.[9] We note again that the negative of Messier 13 was exposed for eleven hours, and that, on account of better atmospheric conditions and of longer experience with the improved plate-carrier, the smallest images are 1".03 in diameter. Taking rigorous account, first, of the greater intensity of the smaller images, and second, of the greater exposure-time, in accordance with Schwarzschild's law, we find that the gain in the photograph of Messier 13 over that of Messier 3 should be 1.3 magnitudes.[10]

Among all of the author's photographs, only two show fainter stars than those on the negative of Messier 13. My photographs of N.G.C. 6995 and N.G.C. 6960 *Cygni*, taken with the 60-inch reflector on the nights of July 1, 2, 3, 4, and 5, 1910, with very fine atmospheric conditions and with very long exposures, show minute stars which are almost exactly central in the photographs; for this reason these minute stars are probably decidedly fainter than 21.3 magnitude.

The original negative shows this cluster to be at least 30′ in angular diameter.[11]

Let us now consider the results which we may expect to secure in photographing the same cluster with a Ritchey-Chrétien reflector, but with aperture, focal ratio, photographic emulsion, atmospheric definition, exposure-time and all other conditions like those used in making the Mt. Wilson photograph as described above. We would, of course, use the concave photographic plates and the mechanical refinements of cork-covered (or approximate-*invar*) tube; constant-temperature chamber with small refrigerator; equatorially-mounted observer's carriage, etc., as previously described. These refinements are the standard equipment of the new type of reflector, in order to *utilize* the better star-images; they have been so regarded by the inventors since 1910.

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[9]G. W. Ritchey, *Monthly Notices R.A.S.*, Vol. 70, 1910, page 624.

[10]K. Schwarzschild, *Astrophysical Journal*, Vol. 11, 1900, page 89.

[11]Shapley's estimate of the distance of Messier 13, based chiefly on the study of the Cepheid variables in it, is of the order of 35,000 light-years; the corresponding diameter of the cluster is of the order of 350 light-years.

In the following paragraphs the term *telescopic images* refers only to the star-images produced by the telescope; while the term *photographic images* refers to those on the finished negative.

With the two telescopes of 50 inches aperture which we are considering, and at distances from the optical axis with which we are concerned in photographing Messier 13, the ratios of diameters of the telescopic star-images of the Ritchey-Chrétien to those of the Newtonian in the flat field are very nearly as follows: at 2′.5 from the axis, as 1 to 4; at 5′, as 1 to 5; at 10′, as 1 to 4; at 15′, as 1 to 4; at 20′, as 1 to 3.5. The corresponding ratios of *surface-intensities* of the telescopic images are therefore at least as 16, 25, 16, 16 and 12 to 1, respectively, in favor of the Ritchey-Chrétien. The ratios given take account of the combined effects of aberration-figure and diffraction, but not, of course, of the effect of atmospheric definition. With the very small, intense star-images of the new type of telescope we shall well afford, on nights of good "seeing", to eliminate all intervals of inferior definition.

Resting his opinion upon long experience in astronomical photography, and upon the fact that every basis of this comparison has been investigated in the laboratory, the writer is convinced that with equal quality of atmospheric definition the 50-inch Ritchey-Chrétien telescope will enable us to photograph out-of-axis stars which are *at least* two magnitudes fainter, and will give us out-of-axis images on the negative at least two and one-half times smaller in diameter than those of the Mt. Wilson photograph. In addition, the new negative will permit much greater accuracy of measurement, for two reasons: first, the photographic images will be smaller, more symmetrical in form and more intense; second, since the telescopic images are nearly symmetrical in form and illumination, the apparent *positions* of the images on the negative will not be appreciably affected by the *brightness* of the stars photographed, as they are in all negatives taken with Newtonian reflectors.[12]

[12]With the better locations for observatories which have been found, and with the further improvements of methods of astronomical photography, which will be briefly described in this series of articles, the gain in smallness of photographic images and in the faintness of stars photographed will be more nearly in proportion to the improvement of the telescopic images as given in the preceding paragraph.

If we now examine Plate IX noting that the expression "two magnitudes fainter" used in the preceding paragraph means 6.3 times fainter, we may gain some comprehension of what we may expect to see in the new photograph. The fact that the photographic images in the inner field will be much smaller will result in relieving to a great extent the superposition of the images there; and this despite the fact that the very small images of enormous numbers of still fainter stars will be present. The fact that the telescopic images of the outer field will be much smaller and much more intense will result in the outer field of the photograph being enriched by the very small images of tens of thousands of faint stars which are not recorded on the Newtonian photograph. The presence of the images of these faint stars will call our attention sharply to the fact that the real dimensions of the cluster are much greater than those indicated by a superficial study of the Newtonian photograph.

A comparison of the two negatives will show also that, in attempting to deduce the true rate of decrease in the number of stars per cubic unit of space as we go outward from the center to the boundary of the cluster, we must either take rigorous account of the effects of aberration of the out-of-axis telescopic images, or we must make a series of photographs in which a number of points at successive distances from the center of the cluster are brought, in the successive photographs, to the optical axis of the telescope.

Many known facts in regard to the globular clusters indicate that each of the larger of them contains millions of stars. The author expects to prove by direct photography that this is true. This particular result in regard to globular clusters is only used as an example. The important point is that the combination of methods which will produce this result will also give us photographs of a quality which will permit much greater accuracy of measurement in many departments of astronomy, including spectrography, than has hitherto been possible. These methods, of which the aplanatic reflector is an example, are those of economy, of efficiency,

of technique and of invention. They are of the kind which will be available for *every* observatory, not alone for a few great observatories. I emphasize that the methods are those of great refinements, fully as much as of great sizes. We should note that such inventions as the light, cellular, ventilated construction, which permits the use of small units of low-expansion glasses for very large mirrors; the short, compact, equatorial mounting and small dome made possible in the Ritchey-Chrétien reflector; and the fixed, vertical, universal type of reflecting telescope recently described in this JOURNAL,—all of these render practicable not only great refinements but also great sizes of telescopes and of their accessory instruments, to a degree which has not been possible by methods hitherto known.

Figure 2 is a schematic drawing of a 6-meter (19.7 feet) Ritchey-Chrétien equatorial, with its dome, building, *equatorial* observer's carriage, *exterior* tube-extension, etc. The dome required for this telescope of six meters aperture is but little larger than the greatest observatory domes now in use in the United States.

It is perhaps well to summarize very briefly the chief advantages of the Ritchey-Chrétien compact equatorial type of reflector as compared with a modern Newtonian equatorial: (a) The length, weight and cost of the tube are reduced to one-half. (b) The weight and cost of the entire telescope mounting are substantially reduced. (c) Temperature-protection of the tube during the night, (while in use), is rendered practicable. (d) Temperature-protection of the entire telescope, including the mirrors, throughout the day, is rendered practicable. (e) Flexures of the tube are decreased to one one-thousandth part. (f) Convenience of quick interchange of mirror-combinations is substantially increased. (g) An *equatorial* observer's carriage is rendered practicable. (h) An *exterior* tube-extension is rendered practicable. (i) Diameter of dome is decreased to one-half. (j) Weight and cost of dome are decreased to one-eigth. (k) Diameter of building is decreased to one-half. (l) Weight and cost of building are decreased to one-third. (m) The surface-intensity of out-of-axis star-images for needed fields is increased sixteen-fold. (n) Symmetry of form

and consequent measurability of all out-of-axis star-images are very greatly increased.

Some Astronomical Laboratories

While the author was a student in Cincinnati University and assistant in Cincinnati Observatory, he established his first astronomical laboratory at his home in Cincinnati. There the first elaborate model of his mechanical flotation-system for large optical mirrors was made. In 1888 he moved his laboratory to Chicago, where for eight years he developed many of the refinements of optical work, of optical tests for telescope mirrors, of reflecting-telescope design, and of photographic methods, which he used later in his work at Yerkes and Mt. Wilson Observatories.[13] In his Chicago laboratory he completed his first 24-inch mirror, which later became the principal mirror of the 24-inch Yerkes reflector.[14] This mirror was made from a fine St. Gobain disk, and at that time the author's acquaintance with M. Delloye, now Director-General of the St. Gobain Glass Companies, began.

The greater part of the author's astronomical work since 1910, and especially since 1919, has been done, with the aid of his son and an assistant, in his private laboratory in California. There the first cellular, ventilated optical mirrors were constructed, of selected, polished plate-glass, up to 20 inches diameter; some of these have been successfully tested through many years for optical permanence. There the first small pair of Ritchey-Chrétien mirrors was successfully made and tested, but not mounted.[15] There improved methods of optical work for very large mirrors were experimentally developed, which the author used later in figuring the 60-inch plane mirror and the 101-inch paraboloidal mirror of Mt. Wilson Observatory. There most of the improvements for astronomical photography briefly described in this series of papers were first demonstrated on a moderately large scale. There the photographic

[13] Astrophysical Journal, Vol. 19, January 1904, page 53.

[14] *Astrophysical Journal*, Vol. 14, November 1901, page 217.

[15] A grant was received from the Rumford Committee for the optical work of these mirrors.

apparatus for highly-magnified telescopic images, and the two double-slide practice-machines soon to be described in this series of papers were developed. There the special Benecke photographic emulsions for astronomical photography were gradually improved; their sensitiveness and their fineness of granulation were both, simultaneously, more than doubled, and what is more important, the general methods for much greater improvement were slowly and laboriously evolved during 13 years. There the methods of grinding and polishing, in multiple, circular, concave glass plates, and of coating them uniformly with photographic emulsion, were developed. There the first small, extremely accurate measuring-machine for concave photographic plates was designed. There the designs of the first fixed, vertical, universal reflecting telescope and the designs of the first compact Ritchey-Chrétien equatorial telescope and its accessories, were worked out.

Many of these improvements originally had been planned by the author, with the collaboration of his father, James Ritchey, in 1909, 1910 and 1911 for the 101-inch Hooker reflector, in large part as a result of experience in using the 60-inch reflector, and with the urgent approval of Mr. Hooker.[16] First, they were to be thoroughly tested on a comparatively small scale, in a comparatively short time, with Mr. Hooker's generous financial support. If successful, they were again to be thoroughly tested on a larger scale. If again successful, they were to be embodied in the design, construction and use in astronomical photography of the 101-inch Hooker reflector, this design and construction having been in the author's direct charge at that time. Mr. Hooker's sudden death in 1911 prevented all possibility of these improvements being carried out for that telescope. It has required more than fifteen years for the author to bring these improvements to their present stage of development with the resources of a small, private astronomical laboratory, and later with the kind and appreciative assistance which he has received in France. Many related improvements, of equal importance in astronomical photography, still await completion.

[16]Ritchey, this JOURNAL, July-August, 1928, pages 212 and 213.

One form of Schwarzschild telescope. In 1910 Schwarzschild requested me to assist him in putting into practice some of his optical inventions. We discussed his type of aplanatic reflector, and especially the form illustrated in Fig. 8, No. 4, page 219, of my paper in the July-August number of this JOURNAL. In this form the distance between the two mirrors is equal to twice the equivalent focal length of the telescope. This form is superlatively important; it is unquestionably the best combination of two mirrors ever devised, so far as the smallness of the out-of-axis images, alone, is concerned. But this telescope is very long, its field is *convex*, and a considerable percentage of the cone of light reflected from the large mirror is obstructed by the photographic plate and its cell. Schwarzschild said to me: "It is in some respects the best form, but there are prohibitive difficulties in its construction and in its use. The convex field is *too* difficult; yet I will not consider using a correcting-lens to flatten it, because that would be an abject confession of failure. I am more than ever determined on this point, after seeing the excessively faint stars shown in your photographs. The process of coating convex plates uniformly with sensitive emulsion will be difficult,—perhaps impossible. And since the field is inaccessible, how can I ever hope to use the refinements of guiding, refocusing, etc., which you use with the 60-inch reflector?"

I had already considered these same questions, and was able to tell him of one solution of the difficulty of the convex field which I had found; namely, that by using thin, circular, ground and polished, spherically-curved plates with parallel surfaces, made preferably of borosilicate crown glass, with their curvature to coincide with that of the convex field, coating these plates with sensitive emulsion on the *concave* side, (which is *not* difficult), and using them in the telescope with the *convex* face toward the incident light, most of the difficulties of the convex field disappear. I said also, that by using the long, awkward telescope as a vertical, fixed one, with coelostat, and by using the horizontal, electrically-controlled guiding mechanism, many of the mechanical and observing difficulties also disappear. He said: "You have removed the curse

which always hung over it. *This* is the form which you must make for me." Thirteen years later I finished and tested the mirrors, as decided upon at that time, of a Schwarzschild telescope of this form, in my own laboratory; but I was unable to mount them even in a temporary mounting, because I was called to France. I brought with me to France, and submitted to French astronomers and to M. Dina in April, 1924, my long-considered designs of a fixed, vertical, universal telescope, with coelostat, which embodied, in one great instrument, one Newtonian, three Cassegrainian, one Schwarzschild and one Ritchey-Chrétien complete reflecting tlescopes.[17]

Astronomical Photography with Very High Powers

We should note, in regard to the advances already made in astronomy through the application of photography, first, that we can photograph, with long exposures, very much *fainter* stars, nebulae, spectra, etc., than we can seé directly with the aid of the greatest telescopes. Second, in general, we can secure much greater accuracy by sound methods of measurement of properly-made photographs than by measurements made directly with telescope and micrometer. Third, many applications of photography to astronomical problems, such as those of solar research, of spectrography, of photometry, of the discovery and study of faint variables and *novae*, of photography with ray-filters,—all of these and many others are of very great importance.

But we should note, also, that little has hitherto been accomplished in the direct photography of extremely small details of *bright* celestial objects, such as small, very bright planetary nebulae, the planets and the Moon. These marvellous, small details can easily be detected *visually* with great telescopes, with very high magnifying powers, on the finest nights, at instants of exquisite atmospheric definition. But to *photograph* these finest details successfully requires a high development of mechanical and optical technique. This development has now been accomplished. Three

[17]This JOURNAL, May-June, 1928, page 163.

important points in regard to it should be noted here. First, finer details have been photographed than those which are at the limit of the theortical *visual* resolving power of the optical mirrors used; this of course is due to the fact that the photographic resolving power is higher than the visual, in inverse proportion to the wavelengths of the light utilized. Second, the method was gradually developed and completely demonstrated in the laboratory, not on the sky, for reasons which need not be given here. Third, what is of the highest importance, the refinements of methods employed, which include the use of the double-slide practice-machine, are applicable to, and will greatly improve, direct astronomical photography of every kind. This, in turn, will inevitably permit a great increase of accuracy of measurement of astronomical photographs, which is the *ultimate* purpose of all of the author's efforts in astronomy.

Whether the increase of accuracy of astronomical measurement which will result from all of the improvements now demonstrated shall prove to be small or great, whether two-fold or ten-fold, there can be no question that this work should be continued by demonstrations on a large scale, and should be extended to other related improvements already begun, with the aid of a well-equipped, well-supported astronomical laboratory. This work is not alone that of an inventor, nor of a telescope-builder, nor of an optician, a glass-maker, a mechanician, a mechanical engineer, a photographic-emulsion maker, an astronomical photographer, a measurer of astronomical photographs, an astronomer. It is not higher than, but *more than* the work of any one of these. It is the work of all of these together. It will be classed in the future, not above, not below, any other long-continued, homogeneous research for perfecting fundamental scientific knowledge. It is to be hoped that, in the future, when the inventions made for this ultimate purpose are utilized by others, and when the astronomical photographs made in the course of, and as an important part of the attainment of this ultimate purpose are *sent out* and are *published* by others, this work will receive the same acknowlgment and credit which are honorably accorded to any other kind of scientific work.

A prominent astronomer once said to the author: "All matters

of mechanical, optical and photographic technique, and even the theories of these subjects, are *as a sealed book,* to me; I regard these matters as belonging solely to the domains of the mechanic, the optician and the commercial photographer; my own interests are wholly intellectual."

In the next article of this series I shall describe a series of visual observations with the 40-inch Yerkes refractor and with the 60-inch Mt. Wilson reflector, and the resulting invention of a practice-machine and of a horizontal, electrically-controlled guiding and occulting mechanism for astronomical photography with very high powers.

Paris' Observatory, August 4, 1928.

THE PROBABLE EPICENTRE OF THE SAINT LAWRENCE EARTHQUAKE OF FEBRUARY 5, 1663

By Ernest A. Hodgson[1]

(A Paper presented to the Royal Society of Canada)

It is generally supposed that Canada is one of those fortunate countries which are not subject to serious earthquakes. This is, comparatively speaking, true. On the other hand, an examination of available records serves to show that earthquakes, which must be classed as being of destructive intensity, occur at fairly regular intervals in Eastern Canada.

For several years past the seismological division of the Dominion Observatory has been making a sustained effort to index all available information with regard to these earthquakes. It has been found that severe earthquakes have been reported as having been experienced, at intervals of approximately sixty years, in the area which may be roughly designated as the Saint Lawrence valley.

Further study of the records[2] seems to indicate that, with the possible exception of two severe earthquakes, the epicentres of these major tremors coincided rather closely with that of the Saint Lawrence earthquake of February 28, 1925, which was found to be $\phi = 47°.6$ N: $\lambda = 70°.1$ W. Quoting from the paper presented last year[3] this is "in the Saint Lawrence between the mouth of the Malbaie river on the north and the mouth of Rivière Ouelle on the south, it being understood that the epicentre is not to be considered as a point but rather as a zone the major axis of which lies approximately north and south (mag.) and having a mid-point at the position indicated by the above co-ordinates".

One of the two possible exceptions is the earthquake of

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[2] The greater part of the material utilized for study in connection with this paper is scattered through the seventy-three large volumes of the Thwaites translation of the Jesuit Relations. The work of checking over these volumes, selecting, copying, and finally typing many pages of references obtained therefrom has been done by Miss A. I. Dearth, of the staff of the seismological division of the Observatory.

[3] The Saint Lawrence Earthquake, February 28, 1925, by Ernest A. Hodgson. Transactions of the Royal Society of Canada, Third Series, Volume XXI, Section IV, 1927. See page 149.

September 5, 1732. It is quite possible that the epicentre of this shock was very much closer to Montreal than indicated above. However, a further study of the records may indicate that the damage reported from Montreal may have been partly due to other causes, and that this epicentre also lay below Quebec.

The other exception is that of the earthquake of 1663. Appended to this paper will be found a list of all the documents so far discovered in which reference is made to this shock. This paper, which is of a preliminary nature only, is presented at this time for the following reasons:—to announce the work of investigation being carried on as regards historical references to the earthquake of 1663; to indicate our present sources of information; to request the co-operation of others in bringing further references to our attention; and, finally, to outline in a brief and general way the tentative conclusions now being considered and critically examined. These conclusions are all, more or less intimately, based on the analysis of the location of the epicentre.

We shall consider, in order, the following topics:

(i) The types of documentary records.
(ii) Documentary circumstances which tend to warrant a discounting of any impressions of extraordinary severity.
  (a) The original authors and their environment.
  (b) Quotations by later writers.
(iii) The reported destruction near Three Rivers, and its probable explanation.
(iv) Tentative conclusions from the study, to date.

The Types of Documentary Records

The reports of this early disturbance are given, for the most part, in letters and reports of the Jesuit missionaries who were labouring in Canada at that time. The outstanding and more frequently quoted "Relations" are those of Father Jerome (or Hierosme) Lalemant, and Father Charles Simon, respectively, but there are others which may be classed as "original" reports, in the sense that they were written at or near the date of the earthquake, although many of the details given were not always directly observed by the writers themselves.

Besides these there are very many reports which we may designate as "secondary." These are translations of the earlier writings, sometimes very much in the form of the originals, at other times appearing as rearrangements and new combinations of those accounts.

An analysis of the literature so far discovered leads to the belief that we must discount the indications of very unusual severity for several reasons. These reasons may be grouped as being, respectively, documentary and physiographic.

Documentary Circumstances Which Tend to Warrant a Discounting of Any Impressions of Extrordinary Severity

(a) The original authors and their environment: The training of the Jesuits who wrote the bulk of the original accounts of this earthquake differed widely. Father Lalemant, for example, is said to have been a fully trained Jesuit priest of wide experience, who was afterwards recalled to France and there made Provincial of the Society of Jesus. On the other hand, Father Simon is reported to have been a Jesuit who was sent out to New France to do mission work, after having received only a limited training. He was in Canada but one year (1662-1663), after which, returning to France, he wrote his account of the earthquake "in the vernacular speech". This was later translated into Latin by Father Ragueneau[4].

A careful examination of the writings of the two men (Lalemant and Simon) will reveal a striking difference in the nature of the phenomena reported. That written by Father Lalemant is comparatively reserved and quite probable. Some parts of that accredited to Father Simon are not so readily believed in all their details.

This does not, however, in any sense imply a lack of good faith on the part of Father Simon. As one who has had an opportunity of seeing at first hand the excitement following a quake of major proportions in this area and of tracing back the many rumors of extraordinary phenomena (currently reported as having been experienced by citizens of repute) to their sources, only to find that

[4] Notes to Volume XLVII. Thwaites translation of the Jesuit Relations.

these were either wholly unfounded or had been grossly exaggerated in circulation, the author of this paper must beg to remind those who read these early accounts, of the circumstances which then obtained.

Transportation and intercommunication were quite limited. Several languages were concerned in the compiling of reports. Many of the early settlers, other than the clergy, were quite untutored, and the Indians were but superstitious savages. Add to this the undoubted facts that there really was a severe earthquake, that earthquakes were not a common experience of either the French or the Indians of that generation (major earthquakes in these regions are felt, as has been stated, at only relatively long intervals —sixty years or so), that, as we shall see, the physiography contributed other factors which made possible some of the more fantastic reports, and one must concede the difficulty a man of limited experience in the new country must have had in separating the real from the imagined, when recounting the extraordinary circumstances through which he had passed during his single year of mission work in the new country.

(b) Quotations by later writers: A second point with regard to the sources of the accounts which would tend to make the circumstances seem more extraordinary is that most of those of the secondary type are a regrouping of earlier writings, which have been translated, re-translated, and even translated yet once again. Coupled with this regrouping and multiple translating of the earlier accounts we must not neglect to examine the possible motives of the compilers of these secondary reports. The material selected *must* make a good story. This accounts for the juxtaposition of hitherto quite discrete items, adding thereby to the "heart interest" perhaps, but tending to exaggerate the effect.

The more serious offense, however, is the omission of "aside" remarks by the original author such as the following, chosen hurriedly from the Thwaites translation of Father Simon's story, which are usually omitted in secondary reports:—"Men know not what to resolve upon in the emergency, or what were best to be done in such circumstances and at such a time; as is always the case in sudden catastrophes and panics, they are deprived of the

liberty of both judging and choosing at the dreadful sights on every side." . . . . "Moreover, what each one's own fear and alarm invented to his fancy, and represented as plausible truth, tormented him just as seriously as if it had been real." . . . . "They add that they saw in mid-air a young man, holding a torch, and prodigies much more wonderful than these; either they really saw these things, or, as happens in troubled circumstances, thought they saw them."

The Reported Destruction Near Three Rivers and Its Probable Explanation

There are other accounts of devastation caused by this earthquake which have been considered pure imagination or exaggeration, on the one hand, or evidence of extraordinary intensity on the other, but which admit of a third explanation. We may quote, again from the Thwaites translation, as follows: "War seemed to be waged even by the mountains, some of them being uprooted, to be hurled against others, and leaving yawning chasms in the places whence they had sprung. At times, too, they buried the trees, with which they were covered, deep in the ground up to their topmost branches; and at other times they would plant them, branches downward, which would then take the place of the roots." . . . . "According to the report of many Frenchmen and savages, who were eye-witnesses, far up on our river, the Three Rivers, five or six leagues from here, the banks bordering the stream on each side, and formerly of a prodigious height, were levelled—being removed from their foundations, and uprooted to the water's level. These two mountains, with all their forests, thus overturned into the river, formed there a mighty dike which forced that stream to change and to spread over great plains recently discovered. At the same time, however, it undermined all those displaced lands and caused their gradual detrition by the waters of the river, which was still so thick and turbid as to change the color of the whole great Saint Lawrence river. Judge how much soil it must take to keep its waters flowing constantly full of mire every day for nearly three months." . . . . " . . going down to Three Rivers, . . . The earthquakes were still continuing there, severe and alarming shocks

having been felt ever since the 5th of February; and yet we were well along in the month of July. The great trees hurled down into the river, together with whole hills and mountains, were still rolling about in a frightful manner in those waters, which continued to cast them up again on the bank in strange confusion." . . . .

It seems unnecessary, perhaps impracticable, at this time to draw a line between the possible and the impossible. The above quotations come well within the former class if we pay some attention to the physiography of the Saint Lawrence lowland. Marine clays, in beds sometimes hundreds of feet thick, are to be found throughout that area. These are peculiarly subject to landslides of considerable proportions[5]. The violence of the earthquake tremors is felt much more strongly, other things being equal, on deep deposits such as these than on solid rock. It is interesting to read in the "Relations" translated by Thwaites that the intensity of the shocks was such that "in the more elevated places the motion was less than in the level country." It is altogether possible that the earthquake was accompanied, in the Three Rivers region for example, by landslides of such magnitude that the above descriptions are not out of place. It is well, too, to remember that the word "mountain" is, even in our day, a somewhat indefinite one. It must also be observed that we are dealing with a translation of the word used by the original author. These considerations render the reports more plausible.

An analysis of old documents making reference to the destruction near Les Grès (on the Saint Maurice river a few miles above Three Rivers) written, in French, by Benjamin Sulte[6] and recently translated into English by J. H. Lefèbvre[7], offers the following

[5] The Marine Clays of Eastern Canada and Their Relation to Earthquake Hazards, by Ernest A. Hodgson, Journal of the Royal Astronomical Society of Canada, September, 1927, pp. 257-264.

[6] Un Niagara Disparu, by Benjamin Sulte. Bulletin de la Société de Géographie de Québec, Volume 5, No. 3. mai et juin 1911. pp. 205-211.

[7] A Niagara Vanished, a translation by J. H. Lefèbvre of Un Niagara Disparu, by Benjamin Sulte. This translation was presented as a paper at the Third Annual Meeting of the Eastern Section of the Seismological Society of America, at the University of Virginia, Charlottesville, Va., on May 1, 1928. It is published in the Bulletin of the Siesmological Society of America, Vol. 18, No. 2, 101-109, June, 1928.

explanation of the destruction reported. Quoting, in part, Lefèbvre's abstract: "The paper reviews certain old documents dealing with conditions in the valley of the Saint Maurice river from 1649 to 1663. In Part I the point is made that, under date of 1649 and 1651, we have evidence that a notedly high waterfall existed between Shawinigan Falls and Three Rivers, at Les Grès. . . . In Part II extracts, from documents relating to the earthquake of 1663, show that there was a considerable and serious disturbance on the Saint Maurice near Les Grès, and that the once-noted waterfall—a "second Niagara"—was not to be found after the earthquake. The author of the original paper points out the fact that the deep clay deposits in the region are gradually rendered unstable by the action of water, and offers the opinion that the destruction in the valley of the Saint Maurice and that of the Batiscan was due only in part to the force of the earthquake, in part to the nature of the terrain —an opinion with which later events and the results of investigation are quite in accord."

Amplifying the bare explanation offered by Benjamin Sulte we should require a sequence of events somewhat as follows:—At the close of the Ice Age, the retreating overburden permitted a gradual rise of the Saint Lawrence lowlands from below sea level. The great level plain of marine clays thus emerged, mantling the extremely irregular features of the ice-scarred rock surface. Here and there in these areas we find glacial drift in irregularly shaped deposits. It is possible that a deposit of this—a drift barrier—crossed what is now the valley of the Saint Maurice near Les Grès and that it was of sufficiently heavy material to form a dam across the valley of that stream then being slowly cut through the deposits. Thus there was formed the waterfall—the "second Niagara" of which mention has been made.

This dam was gradually weakened by the erosion of the softer clay from the upstream side. At the time of the earthquake conditions were developed to a point where the demolition of the waterfall was imminent. Indeed a slide may even have taken place previous to the earthquake, as has been found to be the case in connection with slides which really happened to precede the quake

of 1925, but which were commonly reported as having been caused by that shock.

Whether it happened at the time of the quake or simply near enough to that time that the next group of travellers noticed the results and attributed it to that cause, the dam simply slid forward into the depression below, which had been carved out by the waterfall, the clay hills on either side followed, and the conditions, as reported, were the result.

Such a major slide in the valley of the Saint Maurice, together with other slides of lesser magnitude on the Batiscan and along the Saint Lawrence, seem to be the probable explanation of the devastation reported. The discoloration of the Saint Lawrence seems well established. The overthrow of tree-covered hills in various localities undoubtedly took place. The clay deposits, rather than any altogether extraordinary intensity of the earthquake tremors, seem to have been the cause of much of the upheaval. We are told by Father Lalemant that, "This time was remarkable, among other things, for a frightful and sudden earthquake. It began half an hour after the close of benediction on Monday, the 5th of February, the feast of our holy martyrs of Japan, namely, at about 5-1/2 o'clock, and lasted about the length of two misereres. It took place again at night, and was repeated many times on the following days and nights, sometimes more and sometimes less violently. *It injured some chimneys and caused other slight losses and damages, but did a great deal of good to souls;* for on Shove Tuesday and Ash Wednesday one would have said it was Easter Sunday, so many Confessions and Communions were there, and all devotions frequented." Let us not neglect to note the slight damage caused to the buildings, and at the same time the excitement and terror of the people. Again we find evidence supporting the contention that the actual earthquake intensity was not incomparable with that of 1925.

Let us read, too, from Father Simon's account, reported by Thwaites: " . . . the Earthquake was rather a Scheme of Divine Mercy than a scourge of Justice,—especially since, in so great a confusion of affairs and perturbations of the elements, no one lost life or fortune. Fear came to all, penalty to none."

Tentative Conclusions from the Study, to Date

The study of the documentary evidence thus far would lead to certain tentative conclusions which are being critically examined in the light of each added bit of evidence. Although recited dogmatically in the following tabulation, they are not, by any means, completely established by the evidence to date. We are led to believe, however, that:—

(1) The actual seismic intensity of the earthquake of February 5, 1663, was not incomparable with that of the disturbances of September 5, 1732; December 6, 1791; October 17, 1860; October 20, 1870; or that of February 28, 1925. That is to say, it was not markedly greater.

(2) The documentary reports, while undoubtedly coloured by the excitement and terror of the early settlers, may be accepted to a much greater degree if we consider the possibilities of landslides.

(3) Landslides are obviously aggravated by a previous wet season. It becomes, therefore, a matter of extreme importance to examine carefully all available accounts with a view to establishing the meteorological conditions in Canada, during the fall of 1662. This evidence would have considerable bearing on the question of whether the reported disturbances (if real) were due to landslides or to unusually severe seismic tremors.

(4) The reported devastation near Three Rivers and in the valley of the Saint Maurice does not, in all probability, indicate a separate focus there, but was due to a landslide of major proportions in that valley.

(5) There seems to be a reasonable basis for the assumption that the epicentre of the earthquake of February 5, 1663, lay below the city of Quebec, near that of the earthquake of 1925. We read, for example, from the wrtiings of Francis Mercier (1665) that, " . . . Two highly trustworthy Frenchmen, who have traversed the whole coast of Malbaye (down to Tadoussac is indicated) made the assertion that the Relations of the year 1663 (Lalemant) had only half described the ravages wrought by the earthquake shocks of that region".

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   A translation into English, entitled A Niagara Vanished, has been made by J. H. Lefèbvre, and presented as a paper at the Charlottesville meeting of the Eastern Section of the Seismological Society of America, May 1, 1928. It will appear in the Bulletin of the Seismological Society of America, Vol. 18, No. 2, 104-109, June, 1928.

Note: Such other references as are on file at the Dominion Observatory indicate only earthquake catalogues in which the earthquake of 1663 is merely tabulated along with many others of other locations and dates.
Dominion Observatory,

Ottawa, Canada.
May 15, 1928.

A REVISION OF THE ORBIT OF BOSS 809

By W. E. Harper

The orbit of this spectroscopic binary was published in Volume IV, Number 4, of our observatory Publications and in it the writer deduced a period of 11.422 days. The work was completed in April, 1927, but the publication was distributed only recently.

It has been brought to my attention by Dr. Alexander Pogo of the Yerkes Observatory, that the published period does not suit the observations as well as a period just slightly under one day. While the writer has been long aware of the possibility of alternative periods slightly greater or less than the even day and related to the main one and has usually tested for the same before accepting any as final, it would appear that in this case he has been guilty of this omission.

A graph of the observations made by Dr. Pogo using a period of 0.9172 days showed much better agreement than was the case with the published period and, as he suggested, the agreement could possibly be improved by minor adjustments to his value of the period.

Moreover, six observations, omitted from the first determination by reason of the large residuals they gave, fall into line when plotted according to the short period.

A new determination of the orbit has accordingly been made. From the first plate made Nov. 22, 1918, to the last one secured two nights ago, Aug. 27th, there have elapsed 3,888 cycles and a period of 0.9171877 days satisfies all 36 observations. A sine curve seems best and on this assumption of a circular orbit the remaining elements are found from a least-squares solution.

Velocity of system	γ	+2.30 km./sec.
Semi-amplitude of range	K	95.61 km./sec.
Epoch nearest the sun	(T)	J.D. 2,421,191.9863

The probable error of an average plate, which in the original solution was ± 6.4 km. per sec., has by the use of this shorter period and new solution been reduced to ± 3.3 km. per sec. This in itself would be sufficient justification for the acceptance of the shorter period. To further strengthen the evidence though, a plate was made August 27th at a time when the predicted velocities according to the two different periods would have been markedly different. The measured velocity was less than one km. per sec. different from that computed on the short period basis, whilst on the longer period basis the residual was 68 km. per sec.

The evidence is overwhelming then in favour of the short period and my thanks are due Dr. Pogo for his prompt detection of the error and his communication of the same. A more detailed statement will be given in one of our Publications.

Dominion Astrophysical Observatory,
August 29th, 1928.

PAPERS PREPARED FOR THE WEEKLY SEMINAR OF THE DOMINION ASTROPHYSICAL OBSERVATORY

Seminar Talk No. 60.

THE INTERPRETATION OF SPECTRA

Attempts to interpret spectra in terms of atomic structure date back to the work of Boisbaudran and Stoney in 1869 and 1871. The modern era in spectroscopy, however, had its origin in the work of Bohr[1], who applied the quantum theory to the spectrum of hydrogen and was able, on the basis of Rutherford's model of the hydrogen atom and the known values of atomic constants, to derive the frequencies of the Balmer lines. The physical concepts which form the basis of Bohr's theory have been applied in a general way to the spectra of more complicated atoms. The analogy between the spectrum of hydrogen and the spectra of the alkali metals and of other elements whose spectra show extended series has led to the explanation of the terms occurring in the spectra of these elements, as being due to energy levels in the atom corresponding to successive orbits occupied by the valence electron.

It was at first believed by many investigators that the azimuthal quantum number of a term was determined only by the nature of the orbit occupied by the outermost electron of the atom. While this view completely accounted for the terms in the spectra of the alkali metals, it proved less satisfactory in the case of elements showing triplet and singlet series and was quite inadequate to explain the arrangement of terms of atoms showing more complicated spectra.

More recently a series of brilliant investigations by Russell and Saunders,[2] Heisenberg,[3] Hund[4] and others has disclosed what appears to be the true connection between atomic states and

[1] Bohr, Phil. Mag. 26, 1 and 26, 476 (1913).
[2] Russell and Saunders, Ap. J., 61, p. 38, (1925).
[3] Heisenberg, Zeit. F. Phys., 32, p. 841, (1925).
[4] Hund, Zeit. F. Phys., 33, p. 345, (1925).

spectral terms. The new theory states that the character of a spectral term depends on the resultant of the moments of momenta of all the electrons occupying uncompleted shells in the atom rather than on the orbit occupied by a single electron. Hund had formulated a set of rules by means of which, when the orbits occupied by all the external electrons of an atom are known, the terms in the spectrum may be completely determined. For all, spectra which have been examined up to the present, there appears to be complete agreement between the theoretical work of Hund and the results of experiment. The new theory appears to be equally capable of explaining the complicated spectra of the elements of the eighth group of the periodic table and the relatively simple spectra of the alkalies.

The development of atomic theory to the point where the interpretation of even the most complicated spectrum may be practically complete represents the culmination of the study of spectroscopy extending over a period of fifty years. No single investigator may claim the credit, but the work of Hund and Heisenberg is outstanding and must be reckoned as one of the most remarkable achievements of modern science. Discussions of Hund's theory in the English language have been published by Fowler and Hartree,[5] by McLennan McLay[6] and Smith, and by Russell.[7]

C. S. BEALS.

[5] Fowler and Hartree, Proc. Roy. Soc., 111, p. 83, (1926).
[6] McLennan, McLay & Smith, Proc. Roy. Soc., 112, p. 76, (1926).
[7] Russell, Phys. Rev., 29, p. 782, (1927).

Seminar Talk No. 61.

STATISTICAL DISCUSSION OF SPECTROSCOPIC BINARIES

Review of paper by ARTHUR BEER, *Pub. Berlin-Babelsberg*, Vol. 5, Pt. 6.

The first part of this paper dealing with the Period Amplitude relation was discussed on February 3rd. The second half of the paper considers other frequency values in spectroscopic binaries.

Their frequency and the frequency of double-lined binaries with respect to spectral type and apparent magnitude are tabulated. As is well known, there are greater percentages of spectroscopic binaries among the early types, over 40 per cent. of the *B*-stars being binary, and with maximum frequency between magnitudes 5.0 and 5.5. This is doubtless a discovery effect as all stars fainter than 5.5 have not yet been spectroscopically observed. Their distribution over the sky is quite irregular as there are more than twice as many between 4 and 6 hours, and also between 18 and 20 hours, than between 10 and 14 hours. Also 69 per cent. are north of the equator, this obviously a discovery effect. The distribution over the sphere is illustrated in Plate 4.

The next section of the book contains a list of all the binaries with known periods and known or approximate elements, 301 in number, and Beer sets out to determine the parallax and absolute magnitude of all these binaries. He depends mostly on spectroscopic absolute magnitude using principally Young and Harper's values, but he also uses other methods, such as trigonometric, group motion, eclipsing variables, parallactic motion, etc. The binaries in the above list, after their absolute magnitudes have been thus obtained, are plotted on a Russell diagram, Plate 5, and follow well the characteristic inverted figure 7 form. Plotting binaries with respect to period and type he finds the well-known relation that short periods go with early type spectra, nearly 60 per cent. of *O*6 to *B*4 stars have periods less than 10 days and the majority of stars of periods greater than 50 days are of the later types. The average period for spectral types to *F*5 differs little from 20 days, but for later types increases quickly to 1000 days although the visual binaries show no such relation. There appears when all periods are plotted in Plate 6 to be three maxima at periods 6 days, 140 days, 800 days.

The eccentricity and period eccentricity relation is next discussed, and it is found half the eccentricities of spectroscopic binaries are less than 0.10 while few visual binaries have eccentricities less than 0.30. The eccentricity is greater than 0.5 for 13 per cent. of the spectroscopic and 43 per cent. of the visual binaries. The relation between period and eccentricity is a very curious one, Plate 7, showing a slow increase of eccentricity to

0.05 for periods to 6 days then a rapid increase to $e=0.19$ for periods of 9 days. There is then another rapid rise to an eccentricity of 0.38 at a period of 30 days and an almost equally rapid drop to a minimum of $e=0.24$ at 70 days then a gradual rise to $e=0.33$ at 3000 days where it joins the curve of visual doubles. The sharp maximum of eccentricity of 0.5 in the early type stars for a period of about 29 days is so marked that it must have some physical significance.

Beer refers to the preference of ω for the first and second quadrants first pointed out by Miller Barr, and although further data have made this preference much less marked there are still nearly 50 per cent. more binaries having ω in the first and second than in the third and fourth quadrants.

The longest and most important section in this part of the book deals with the masses of the stars, Table 46 giving the completely determined masses of 41 eclipsing variables and Table 47 the masses multiplied by $\sin^3 i$ of 98 double-lined binaries. The relation between mass and type, the $m \sin^3 i$ being divided by 0.6*L* to give average masses, shows that the masses of stars of types *O*6 to *B*4 are nearly twice the *B*5 to *B*9 and five times the *A*0 to *A*4 stars, while all the remaining types have less than three times the mass of the sun. Among the spectroscopic binaries there is little difference between the masses of giants and dwarfs though in the visual binaries the giants are three times as massive as the dwarfs.

There is little relation between α this ratio of the masses of the components and the type, but generally there is an increase of α with smaller mass. The mass ratio $f=\dfrac{m_2^3 \sin^3 i}{(m_1+m_2)^2}$ varies from .00017 to 13.2 times the sun and consequently cannot be well discussed statistically, but placing $F=\sqrt[3]{f}$ makes it more readily usable. All the binaries with both single and double spectra arranged according to type and value of F are graphically plotted in Plate 8, which shows that in the double lined binaries the mass function f reaches a maximum at 0.19, while in the single lined binaries it is only 0.023. The average f for the former is .213 and the latter .083. Beer shows that this difference is not likely due to different masses or different inclinations of the orbit plane, but is most likely

due to the different mass ratios in the two types. He is able to show that the average mass ratios of the double lined binaries is 0.772 and calculates it for the single lined binaries as 0.463, which difference, when transformed into values of the mass function f, gives this ratio nearly equal to the observed. As a matter of fact this result should follow without analysis as the reason we do not see more double lined binaries is mainly because the mass of the secondary is relatively small as compared with the primary, and the spectrum is hence too faint to be observed.

The whole work is an example of material very carefully prepared and analysis very thoroughly performed. That more definite relations were not obtained is due partly to the scarcity of material and partly, also, probably to the fact that the relations may not be present.

J. S. PLASKETT

Seminar Talk No. 62.

RADIAL VELOCITIES FROM THE LICK OBSERVATORY.

Volume XVI of the Publications of the Lick Observatory entitled *Stellar Radial Velocities* is a monumental number issued about one month ago and containing the results of the radial velocities of the stars obtained at that observatory during the past thirty odd years. Where these results have already been published, as in the cases of spectroscopic binary orbits, the individual observations are not repeated but the velocity of the system is quoted and the reference given.

It was not the purpose of the reviewer to give an exhaustive summary of the book, but rather to sketch certain sections of it and to show how some of the velocities hitherto unpublished affected the results of certain binary orbits determined by himself.

The Introduction gives a historical account of the Doppler-Fizeau principle and its earliest application to the determination of stellar velocities in the line of sight. It will help Canadian readers to recall dates just to remember that such measures of the displacements of lines were first made about the time of our Confederation. At the start such measures were visual, but owing to

the extremely small displacements the results were very uncertain, and it was only after 25 years' effort that reliable results were secured in this way. Keeler's measures of the line of sight velocities of 13 bright-line nebulae represent the high water mark of such visual determinations. With the introduction of the photographic plate marked improvement was effected, and it was just about this time, around 1890, that Campbell conceived the ambitious programme whose completion has given us the volume under consideration.

As statistical studies concerning the motions of the stars, and our solar system relative to them, can only be carried out properly when all portions of the sky have been brought under review, it was early planned to send an expedition to the Southern Hemisphere to secure results for those stars unaccessible from the northern latitude. After many vexatious delays, duly chronicled, the D.O. Mills observatory at Santiago, Chile, was established in 1903. Regarded as temporary only, it has been maintained ever since by gifts from time to time of various individuals. A full description of the various spectrographs at the two institutions is given and briefly, while one and two-prism spectrographs are occasionally used the main one in use was the three-prism with a dispersion of about 11 angstroms per millimeter.

Their method of measurement is fully described. The micrometer engine is used for the most part, and zero settings for all the lines to be met with in the various types of spectra are tabulated. The differences, in any spectrum under consideration, from these standard settings gives the displacement, which is easily converted into velocity. The standard plates used on the spectro-comparator are measured first on the micrometer and minor corrections added later.

Much time has been spent both in observing and computing to have their results accurate. Test objects, whose radial velocities can be computed, are spectrographed from time to time and afford data for corrections to be applied to the results obtained for the stars.

In the 30½ years' work at the northern observatory some 15,000 spectrograms were secured by 31 or more observers, the three main ones being Moore, Wright and Campbell. At the

southern station an additional 10,301 spectra were secured in the 24 years' operations.

The velocities for about 2,600 stars brighter than magnitude 5.51 were secured, and of these 2,149 were used in a solution of the sun's motion, which solution gave a velocity of 19.65 km./sec. directed to the apex $\alpha = 270.6$ and $\delta + 29°.2$.

The bearing of certain velocities on the writer's binary orbits will be chronicled later. W. E. HARPER.

Seminar Talk No. 63.

THE ORIGIN OF THE NEBULAR LINES*

In this paper *Dr. Bowen*, an associate of *Millikan* of the Norman Bridge Laboratory of Physics, California Institute of Technology, gives the identification of the majority of the nebulium lines of heretofore unknown origin. His explanation is that they are due to electron jumps from metastable states in the excited atoms of oxygen and nitrogen.

The spectra of the gaseous nebulae, such as Orion, contain lines of the well-known elements, hydrogen, neutral and ionized helium, ionized carbon, nitrogen and oxygen and in addition those attributed to the hypothetical element 'nebulium' the total number of lines being approximately sixty. None of the 'nebulium' lines (some of the strongest of the nebular lines) have been produced in the laboratory.

Formerly 'nebulium' was considered to have a low atomic weight since the lines are always associated with hydrogen and helium but the modern developments of the atomic structure theory indicate that there is no element of low atomic weight undiscovered. There is no place for 'nebulium' in the periodic table. Moreover, the 'nebulium' lines behave differently in different nebulae, as if they have not a common origin. The conclusion seems inevitable that the 'nebulium' lines are produced by known elements existing in a state which cannot be reproduced in the laboratory, the chief condition for their production being that they are of extremely low density.

*I. S. Bowen, Ap. J. 67, 1, 1928.

Under laboratory conditions, where the mean time between impacts of an atom is of the order of 10^{-3} sec., an atom in a metastable state whose mean life is very long (atom-time scale) before spontaneous emission, will be dropped to the normal *S* state by impact, without the production of radiation. The conditions are very different in the nebulae, where, on account of the excessively small density the mean time between impacts is of the order of 10^4 to 10^7 sec.,—many days. Here an atom in the metastable state will normally return to the *S* level emitting radiation proportional to the difference in energy levels. Similarly the atom may, by absorbing the precise amount of energy, be lifted from the normal *S* level to the metastable *D* and *P* levels, producing the absorption lines observed in the nebular spectrum.

From an analysis of the energy diagrams of the existing atoms of oxygen and nitrogen *Bowen* finds the identification of a large number of the more important 'nebulium' lines. Thus, the strong green pair *N*1 and *N*2 (λλ5007, 4959) are due to exchanges between the *D* and *P* levels of *O* III. The 'nebulium' lines in the red (λλ6584, 6548) are due to similar exchanges between the *D* and *P* levels of *N* II. The *S*-*D* group of *O* II give rise to the ultra-violet lines (λλ3681, 3679).

The author gives an interesting exhibit of line intensities observed in 36 nebulae arranged in decreasing order of the *N*1 and *N*2 intensities. An inspection of the table shows how the lines identified as *O* III behave generally like *He* II having approximately the same ionization potential. Of the lines still unknown two pairs are noteworthy. It would seem that λλ3869, 3967 are due to an element of relatively low ionization potential; but that λλ 3426, 3346 would have a great increase of intensity at the hottest end of the table, evidently coming from an element having a high ionization potential higher than *O* III. The author identifies λ3426 as *N* IV and λ3346 as *O* IV.

Structure of Planetary Nebulae

The second part of the paper deals with the structure of the planetary nebulae. It has long been known through the work of *Wright* that the planetary nebulae when photographed with a slitless spectrograph exhibit series of monochromatic pictures of the

nebulae of various sizes and intensities. Following *Zanstra*, the author explains the production of these images as due to the photo-electric absorption of light whose frequency is greater than the ionization potential of the atom. Considering a planetary whose central star has a temperature of 150,000° C and surrounded by an atmosphere of oxygen of very low intensity, the author shows that the *O* I (λλ3726, 3729, 7325) pictures of the nebulae will be the largest, *O* II (λλ4959, 5007, 4363) the next largest while *O* III and *O* IV will be decreasingly smaller. All the radiation below 160Å will be absorbed by the $O++++$ atom, so that $O+++$ cannot exist in the inner sphere, radiation between 160-225A will be absorbed by the $O+++$ atom, etc. This mechanism gives a series of concentric shells whose diameter increases with the decrease of ionization potentials of the atoms present in them, and thus affords a qualitative explanation of the sizes of the monochromatic pictures of the planetary nebulae.

J. A. P.

Seminar Talk No. 64.

THE DEVELOPMENT OF BAND SPECTRUM THEORY

While a greater degree of mystery surrounds the problems of molecular structure than the analogous problems in atomic structure, the progress of band spectroscopy during the past few years has shed much light on the subject and the success of the quantum theory in explaining the origin of complicated band systems has been truly remarkable.

The earliest suggestion correlating band spectra with the vibrations and rotations of molecules came from Drude. Later Bjerrum advanced a theory based on classical electrodynamics which met with some success in explaining some of the unresolved bands in the infra red. Bjerrum's theory in its original form which predicted continuous absorption or emission over a definite region was obviously incapable of explaining the discontinuous nature of band spectra. Quantizing the motions of molecules was first suggested by Nernst and Lorentz, who proposed to set the

energy of rotation equal to an integral multiple of Planck's constant h times the rotational frequency. They derived a formula in general agreement with the observational data for pure rotation spectra. They were followed by Heurlinger, who extended Bjerrum's theory to explain the so-called electronic bands and who was able to point out the theoretical similarity between the electronic bands and some of the bands in the infra red. Heurlinger succeeded in deriving the general band formula $\nu = A \pm BM + CM$ which is in agreement with the empirical formulae devised by Deslandres and the expressions for the frequencies of band lines obtained from the Bohr form of the quantum theory. The hypothesis of Bohr that the frequencies of spectral lines represent energy differences and are not identical with the frequency of motions of the emitting system was destined finally to displace the semi-classical theory of Bjerrum. The Bohr theory was first applied to the interpretation of band spectra by Heurlinger and Schwarzschild and their work has been extended by numerous later investigators. The frequencies of band lines have been shown to be due to differences of energy in the molecule corresponding to changes in its rotational state (pure rotation bands); to simultaneous changes in its vibrational and rotational states (vibration rotation bands); and to changes in vibration and rotation accompanied by alterations in the electronic configuration of the atom (electronic bands).

Among the more important modern developments of band spectrum theory should be mentioned the success of the Kramers and Pauli form of the rotational energy function in explaining the detailed structure of bands. Their formula takes the form

$$F = \{(\sqrt{j^2 - s^2}) \pm e\}^2$$

and the symbols j, s and e represent respectively the total angular momentum of the molecule, and the components of the electronic angular momentum parallel and perpendicular to the line joining the two nuclei. Another important development has been the discovery by Hulthen of certain combination relations which exist between the frequencies of the different branches of bands composing a system. The use of these relations is of great importance in the assigning of vibrational and rotational quantum number in complicated systems.

A branch of band spectroscopy which is at present receiving considerable attention concerns the electronic configuration of molecules. Some progress has been made in defining the various electronic states, and Mulliken, Richardson and others have assigned definite quantum numbers to electronic levels in the hydrogen and nitrogen molecules. In this connection it is interesting to note that the existence of ionized molecules is believed to be established and a number of known band systems have been attributed to ionized molecules.

A useful survey of the present position of band spectrum theory may be found in the Bulletin of the National Research Council *Molecular Spectra in Gases.*

C. S. BEALS.

Seminar No. 67, April 20th, 1928.

INTENSITIES OF ABSORPTION LINES

A brief account of the determination of the orbits of the spectroscopic components of *A* Persei preceded the discussion of the above subject. It will appear elsewhere in the JOURNAL.

The particular phase of the question dealt with at this time was the work at Harvard during the past few years to secure a method of measuring the intensities of absorption lines applicable more particularly to their great collection of objective prism spectra. Hitherto the relative intensities of lines have been recorded from eye estimates assisted at times by artificial standards. While these eye estimates have served very well for roughly grading the spectra into the various classes and even for more refined work in obtaining criteria for absolute magnitude yet their inadequacy has for a long time been felt by those dealing with such matters. It is evident that a proper interpretation of stellar spectra is not possible without precise measurement of line intensities.

A method widely used to-day is to analyze the spectra by means of a self-registering microphotometer. A beam of light originating from an incandescent lamp passes through the spectrum plate on its way through a thermopile. This light gives a thermo-electric

current, which is indicated by a recording galvanometer. By giving the plate a slow motion longitudinally the current will vary in accordance with the density of the photographic layer. A record is thus made showing all the details of the spectrum under examination. The problem, then, is to relate the density of the plate, as shown by the microphotometer tracings, to the intensity of the incident light. The first method adopted for calibrating the plate was to obtain spectra of a star, using apertures whose areas decreased in a fixed ratio, the exposures remaining constant. By using an aperture ratio of 2 it was found that the intensity of the continuous spectrum adjoining the $H\delta$ line of the star Vega was equalled by the intensity of the central absorption when the aperture was made 4 times as great. In other words, the absorption was only 25 per cent., much less than a casual eye estimate would judge. By thus using a differential method and relating the intensity of the absorption line to the adjacent continuous spectrum sources of error are avoided.

Apertured spectra were thus secured for eleven of the bright stars of types from $E0$ to $K0$ and analyzed by the Moll microphotometer. The intensity differences between background and line, expressed in stellar magnitudes, were thus determined for a large number of the important lines occurring in the spectra and tabulated.

The various possible sources of error are examined in detail. Duplicate tracings are consistent when the microphotometer adjustments are constant. Spectra in poor focus show a lessened depth to the absorption lines, but any such spectrum likely to cause appreciable inaccuracy would be rejected anyway.

The value of the work lies in its application to studies of atomic structure and the conditions in stellar atmospheres. The measurements indicate relationships between intensities of certain lines and absolute luminosities.

W. E. Harper

Seminar Talk No. 68, April 27, 1928.

THE SPECTRA OF THE CARBON STARS*

The deep red stars, the coolest stars accessible to direct observation, are photographically very inactive, sometimes possessing colour indices as high as +4. They apparently terminate the stellar sequence as no spectra have been discovered which may be considered as a continuation of them.

The low temperature of these stars is demonstrated not only by the comparative absence of violet region of the spectrum but also by the absence of any enhanced lines, by the great intensity of such arc lines as *Ca* λ4227, *Na* (*D*) and, of course, by the predominence of a banded spectrum which indicates that the temperature is cool enough to permit the formation of compounds.

The pioneer work on these stars was done by Father *Secchi*, who classified them as the 4th class and who identified the strong 4700A band as due to carbon. Visual observations were made by *Duner*, *Vogel*, *Lockyer*, *Keeler* and *Campbell*, while later, photographic observations were made by *Hale*, *Ellerman* and *Parkhurst* at the Yerkes Observatory. The latter observers identified the chief absorption lines as due to the elements *H*, *V*, *Mg*, *Na*, *Fe*, *Cr*, *Ti*, *Ni* and *Mn*. Carbon exists both in the state of the Swan spectrum and also combined with nitrogen, *i.e.*, cyanogen bands. The most exhaustive study of the spectra of these stars has been made by *C. D. Shane* who, in 1920 (L.O.B. X, 79, 1920) examined the spectra of two representative stars—152 Schjellerup and 19 Piscium—with high dispersion and has lately published an important digest of the spectra of 50 stars of classes *R* and *N*.

In his early work the author found that the spectrum under low dispersion was characterized by an absorption band at λ4700, some 90A wide. Under high dispersion the spectrum is found to consist of a great number of absorption lines and apparently an equal number of emission lines, whose identifications, with the exception of those due to hydrogen, remain unknown. The identification of the absorption lines by the early spectroscopists is confirmed and a few new lines are added. The author concludes that the emission lines, while unexplainable, are real.

*C. D. Shane, L.O.B. XIII, 123, 1928.

A comparison between the spectrum of 152 Schjellerup and the sun-spot spectrum shows that the sun-spot lines appear more prominently in class *N*, indicating a lower stage of ionization.

Observations of a number of class *N* variables undoubtedly show that there is a greater degree of ionization at maximum light than at minimum light. The (*D*) lines which are very broad at minimum light became narrower at maximum light. The strength of the carbon absorption decreases as the light intensity increases and the maximum intensity of the spectrum is shifted towards the red as the light decreases. Such changes are observed also in class *M* variables.

In his recent work he describes qualitatively the behaviour of the characteristic bands of cyanogen, carbon, and hydrocarbon throughout the classes *R* and *N* and suggests a classification of the spectra based upon the relative strength of the cyanogen bands. Some idea of the spectrum may be obtained from the following brief description:—The cyanogen bands (λλ4216, 3883, 3590). Very prominent in class *R*0 rise to a maximum about *R*5, then rapidly decline and disappear about *N*3. The λ4606 cyanogen band previously used as a criterion for classification strangely behaves in an entirely different manner, its intensity slowly varying from type to type. This analogous behaviour remains unexplained.

The carbon bands—the Swan bands (λλ5636, 5165, 4737, 4383) are the most characteristic features of the spectra. *Rufus* (Pub. Det. Ob. 2, 140, 1916) has shown that the progressive increase in carbon absorption exists in two parallel sequences, one for class *R* and one for class *N*. The observations of *Shane* confirm these conclusions if certain intensities poorly scattered in subdivision *R*8 are omitted. If, however, the latter are real the observations indicate a maximum at *R*5 followed by a minimum at *N*0 and a subsequent rise throughout class *N*. The latter interpretation is adopted.

The general behaviour of the hydrocarbon (*G*) band is to increase from *R*0 to a maximum at *R*3 and then to decrease, slowly at first, later proceeding very rapidly and vanishing at *N*3.

The observations of spectral intensity estimated on an arbitrary scale indicate a steady decrease in violet light throughout the classes to the subdivision *N*3, thence the decrease is extremely rapid making it practically impossible to photograph the spectrum beyond λ3900.

The case of *Y CVn e*, type *N*3, Mag. 4.8-6.0 is cited. An exposure of one sec. with a small slitless spectrograph will record the region λ4800, whereas an exposure of 5 hours failed to show any light shorter than λ3900.

One important result of the work is the discovery of the fact that the relative intensities on either side of the Swan band λ4737, *i.e.*, the ratio Int λ4600/Int λ4800 which has heretofore been used as a criterion for the classification of type *N* depends not only on the general faintness in the region of short wave lengths but also upon the strength of the carbon absorption. The curve showing the variation of this ratio throughout the classes bears a marked similarity to the intensity of the Swan band.

Two facts lead the author to believe that temperature may not be the most important feature of this branch of the stellar sequence. Firstly he deduces a black body temperature for *Y CVn e* of 953°K, which is very decidedly too low, and secondly, it does not seem possible that a progressive decrease in temperature or in fact a steady variation in any single physical condition will explain the observed double maxima of the Swan bands.

The following criteria based largely on the cyanogen bands (λ4606 excepted) present a very satisfactory descriptive classification of these stars;—

Class *R*0: Cyanogen bands strong. Spectral intensity distribution as in Class *G* or *K*. Swan bands weak.

Class *R*3: Intermediate between *R*0 and *R*5.

Class *R*5: Cyanogen bands very strong. Considerably weaker in short wave-lengths than Class *R*0. Swan bands very strong.

Class *R*8: Cyanogen bands much weaker than in Class *R*5. Swan bands show a great range of intensity in this class. Spectral intensity distribution intermediate between Class 5 and Class *N*0.

Class *N*0: Cyanogen bands very weak. Spectrum can be photographed as far as *H* and *K* only with difficulty. Swan bands weak or moderate.

Class *N*3: Cyanogen bands missing. Spectrum extremely weak to the violet of 4383A. Swan bands strong.

Class *N*5: Spectrum very faint to the violet of the Swan band at 4737A. Unidentified bands at 4979A and 4686A strong.

Classes *N* 6 and *N*7: Continue in greater strength the characteristics of Class *N*5.

J. A. P.

Seminar No. 74.

CAUSES OF NOVAE

Novae, or new stars, have always been mysteries of the stellar system. Their chief characteristics may be briefly summarized as follows. A sudden increase in brightness, sometimes of 8 or 10 magnitudes in a few days; a gradual decline lasting over several months; composite spectrum, showing radial velocities up to 1800 km./sec. and at the last a Wolf Rayet spectrum with occasionally a visible shell of gas surrounding the star.

In investigating the causes of novae we must consider two possibilities—internal causes and external causes. The first has to do with the physical condition of the star's interior and our knowledge of this is at present not complete enough to enter into a quantitative discussion. Therefore at present we will attempt to consider only causes which arise from something outside the star.

We are now faced with three possibilities:—

1. Collision or near approach of two stars.
2. Collision of a star with a planet or meteor shower.
3. Collision of a star with a nebula.

In regard to the first, a near approach or collision of two stars would undoubtedly create sufficient radiation to produce a nova, but when we take the number of stars in our system and consider the probability of such an event taking place we find that two stars would approach each other to within 100 times the diameter of Neptune's orbit only once in 4×10^8 years. At least one nova is discovered each year so that this explanation does not fit the observed facts.

The second possibility falls down for a similar reason, for we have no evidence of extensive meteoric showers among the stars and Eddington has shown the difficulty of postulating anything but gaseous matter in interstellar space.

This brings us to the third possibility, the collision of a star with a nebula. According to Eddington the density of space is 10^{-24} gm./cc. To satisfy the condition of probability the nebula must be large, about .3 parsecs in diameter as a minimum. Thus it will have no sharp edge and collision will be very gradual, a star at average velocity taking 3000 years to reach the centre. The principal action will be accretion of mass by gravitation which may be calculated from Eddington's formula.

$$\frac{dM}{dt} = \frac{2\pi GM\rho R}{V}$$

where M and R are the mass and radius of the star, ρ is the density of the nebula and V is the relative velocity. A star of solar mass, size and speed would gain 3×10^{14} gm./sec. The energy gained by friction is only a small fraction of the energy normally radiated and may be neglected. The mass lost per sec. by radiation may be neglected in considering the mass gained by accretion in a nebular cloud of density greater than 10^{-19} gm./cc.

If we take 10^{16} gm./sec. as the maximum possible accretion, a star will have a mass equal to a reversing layer added every 28 days. This, however, will not change the mass type since it would take 10^{10} years at this rate to double the mass of the star. The accretion layers will, however, blanket the radiation coming from the interior, which is supposed steady, and it is this cumulative effect that we must investigate.

We consider first the case of a hot star of temperature higher than 10,000 degrees absolute. Such a star will have an extensive chromosphere, that is, an atmosphere almost entirely supported by radiation pressure. The absorption frequencies of the cooler nebula will not coincide with those of the star and the nebular matter will receive the full force of the radiation, becoming a part of the chromosphere. In this case equilibrium will be undisturbed and there will be no nova.

The case of a cool star at a temperature of about 3000 degrees is, however, quite different. The accretion layers will not be held off by radiation pressure but will fall into the photosphere of the star and assume a high pressure gradient. Now an absorbing and reradiating mass takes the place of what was formerly transparent space, the radiative equilibrium is disturbed and the photosphere rises in temperature. The lower pressure appropriate to this state must at once follow or the volume absorption coefficient will rise which again raises the temperature. Thus a highly unstable state will exist and the only result possible is that the star will blow off its outer layers and release in a short time the pent up radiation.

The radiation blanketed before the star's outburst must equal the excess radiation released when the star becomes a nova. By a simple calculation it is found that if a star gradually diminishes 40% in brightness over a period of 200 years, sufficient radiation will be blanketed to cause an average nova. Such a process would require an accretion of $.8 \times 10^{11}$ gm./sec. which is well below the maximum possible accretion adopted earlier.

A good observational test of the theory would be to obtain accurate measures of the star's radiation for a long time before it became a nova. Unfortunately in all but one case such measures are unavailable owing to the faintness of the stars in question. In the case of Nova Pictoris unconfirmed evidence of a slight preliminary decrease of brightness has been found. Should this take place over several hundred years, however, it would be very hard to detect.

At the present there is nothing to contradict this theory of novae and it fulfils the two conditions under which so many theories break down, namely:—

1. Probability of occurrence.
2. Adequacy of cause for the large temporary release of energy.

Reference: M. C. Johnson, *Monthly Notices*, March 1928.

P. M. Millman.

NEWS AND COMMENTS

Dr. Charles Chree, a distinguished authority on terrestrial magnetism and atmospheric electricity, and for thirty-two years Superintendent of Kew Observatory, died on August 12th.

A copy of "Our Wonderful Universe" by Professor C. A. Chant, has just come from the publishers, George G. Harrap and Company, London. This "Easy Introduction to the Study of the Heavens" should find a wide use in the teaching of elementary astronomy. Is not the time ripe for introducing such a course into our High Schools?

"Solar Eclipse Captures Hunter Trials at Aurora," is the heading of a long newspaper clipping sent by a Clipping Bureau as an astronomical item to one of our observatories. (At first glance we thought that our friend Hunter had suggested the capture of the secret of the aurora during an eclipse).

Acting-Director, W. E. Harper, sends in a budget of news from the Dominion Astrophysical Observatory:

The usual tourist traffic has continued this summer with about the same number as last year and reaching its peak in the months of July and August. From sample counts in the summer rush season a couple of years ago it was estimated that 40 per cent signed the Visitors' Book, while at other seasons approximately 60 per cent signed. On this assumption it is estimated that 30,000 visited the Observatory in 1927. During this year about 4,000 visitors came to the Observatory in the first five months, 10,000 in July and 11,000 in August. Among the visitors may be mentioned the following: Professor Henry Norris Russell of Princeton University and Research Associate of the Mount Wilson Observatory, visited the Observatory about Easter and gave a very informative talk on recent spectroscopic work at Mount Wilson and elsewhere.

Mr. R. Meldrum Stewart, Director of the Dominion Observatory, spent a few days with us following the meetings in Winnipeg of the Royal Society of Canada towards the end of May. This

was Mr. Stewart's first visit to the Observatory since it had actually begun operations ten years ago. He gave an address to the staff on "Gravitational Problems."

Professor J. W. Campbell of the University of Alberta made a brief call on June 16th, after attending a mathematical conference in Portland, Oregon. Dr. Campbell spent two summer vacations with us in 1921 and 1922 working on the orbits of spectroscopic binaries.

Dr. Edison Pettit of the Mount Wilson Observatory, who attended the Pomona College meeting of the Astronomical Society of the Pacific, and later addressed the American Society for the Prevention of Tuberculosis at Portland, paid us a visit on June 20. His work on the ultra violet radiation of the Sun shows that the curve representing its variation is similar to that of the sunspots. According to the curves it is just possible the maximum is passed.

Mr. W. H. Browne of the Naval Observatory, Washington, D.C., who was utilising his month's holiday leave to visit the western observatories, paid us a visit one night in the middle of June.

Mr. James Stokley of "Science Service" paid us a visit on August 18th and assimilated considerable information regarding the work of the institution.

Mr. J. A. Pearce, has returned from the Summer School of the University of Toronto, where he gave a course of lectures on astronomy to an unusually large and appreciative class of 39.

Mr. R. M. Petrie, who has spent the past four summer vacations with us, observing and measuring spectra and determining spectroscopic orbits, left at the end of August for the Detroit Observatory at Ann Arbor, Michigan. He has secured a scholarship there and will take up post graduate studies leading to his doctor's degree.

REDeL.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Information Regarding Cool Summers

From Prof. A. J. Henry of the U.S. Weather Bureau, who has investigated the summer temperatures in the United States of the last hundred years, some interesting information is obtained.

At New Haven, Conn., and New Bedford, Mass., the meteorological records reach back over a century. At both places the summer of 1816 was the coolest, but since then there have been at New Haven 29 summers cooler than that of 1927 and at New Bedford there have been 31.

In the western states conditions were quite different. At Portland, Ore., in the last fifty years, the summer of 1926 was the warmest and that of 1927 was next to it. In the records at San Francisco, the summer of 1927 ranks third, only those of 1888 and 1925 having been hotter.

At Lynchburg, Va., Memphis, Tenn., and Cincinnati, Ohio, the summer of 1927 was the coldest in fifty years. At New York, Philadelphia, Chicago, St. Louis and Indianapolis the last summer was second coldest and at Washington it was third coldest.

Prof. Henry also suggests that the temperature of 1816 may have been exaggerated as there is no evidence that the summer temperatures generally throughout the United States were unduly low.

An Amateur's Downfall (Contributed)

As a general rule, I am reduced to seriousness when gazing at the heavens, but the other evening by way of recreation I became somewhat flippant, and lapsed into limerick; the only excuse for which is that versification of this kind aids the amateur in mastering the pronunciation of the names of the various constellations:

"HIGH DOINGS"

Is it true, as they say, that the Sky's getting gay,
That two stars are supporting Altair?
That at fashion's behest, as we might have guessed,
Berenice is bobbing her hair?

Of this we are dubious, but Arcturus is furious
At a sight he maintains is quite clear—
And there's no use in denyin' that spalpeen O'Ryan
Is flirting with Cassie O'Peer.

SCIENCE AND LITERATURE

The following brief discussion is from an address to the British Science Masters' Association by Sir Richard Gregory who is editor of *Nature* and is well known as an astronomer and a physicist: We are not likely ourselves to forget that science and the humanities are the warp and woof of the fabric of modern life any more than we overlook the human factor in industry; but while these relationships are frequently presented to scientific assemblies, we miss the same friendly gestures to science from our literary colleagues. Men of letters tell us that men of science are the only people who have something to say and are unable to say it and we accept the rebuke, even though we know the difficulty of making the intricate process of Nature intelligible in the vocabulary of the ordinary life. Our retort, however, may very well be that men of letters should be expected in these days to know a little of Nature and science and to be able, therefore, to exercise their literary art in displaying the wonder and value of the rare treasures which the argosies of scientific explorers are continually bringing into uor havens from uncharted seas. Science does not want a divorce from literature but closer union with it, and a common understanding of the distinctive qualities by which each can contribute to the fullness of life. It would be easier to mention leaders of science who have enriched literature by their writings than to select men of letters who have exercised their imagination and art upon scientific knowledge and achievement; and we ask those who have the gift of radiant expression to remain no longer outside our temples but to enter and be moved to testify to the revelation which will then be given them. C. A. C.

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